Nitrogen Price and Concentration in the Mississippi River

----Based on WRTDS Model

Research with distinction thesis

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Abstract

The main purpose of this research is to test whether or not there is a relationship between market factors, such as nitrogen fertilizer price and crop prices, and the concentration of nitrogen in the Mississippi River, and how variation in prices affects nitrogen concentrations. This research hypothesizes that market factors also play an important role in affecting nitrogen concentration in the Mississippi River other than flow and seasonal fluctuation.

Using data from USGS measuring eight observation sites along the Mississippi River watershed, this research finds that the relationship between nitrogen prices and nitrogen concentration is negative. Moreover, the elasticity of price change to nitrogen concentration is -0.1 to -0.2, which means for every 10% increase on nitrogen fertilizer price, nitrogen concentration would decrease by 1% to 2%. This research also tested how market factors make an impact in different models.

This research illustrates the important link between markets for nutrient inputs and nutrient outputs in watersheds, and the results suggest that policy makers can use price mechanisms to help reduce pollution.

Introduction

Concerns about the role of nitrogen in watersheds have continued to grow in the United States. Goolsby *et al.* (2000) suggest that the flux of nitrate to the Gulf of Mexico tripled in the last 30 years with most of the increase occurring between 1970 and 1983. Numerous studies have suggested that agriculture is a primary contributor to N in rivers (e.g., Goolsby *et al.* (2001), Turner and Rabalais (1991, 2003), Broussard and Turner (2009)). Sprague *et al.* (2011) suggests that the increasing trend in N levels has strengthened while Stets *et al.* (2015) looked at a longer period and suggested that growth in N concentrations slowed in the Midwestern US after the 1980s, potentially due to reductions in N contributions from agriculture. While N deposition from atmospheric contributions has been important, it appears to have its largest effect in eastern streams (Boyer *et al.*, 2002).

One way to illustrate the link between agriculture and water quality is to evaluate long-term aggregate trends in land use and management and observed trends in downstream river N concentrations (e.g., Broussard and Turner (2009); Stets *et al.* (2015)). A number of authors use a regression approach that models concentrations as a function of time trend parameters (e.g., Dolan *et al.* (1981); Cohn *et al.* (1992); Smith *et al.* (1997); and Goolsby *et al.* (2001)). Hirsch *et al.* (2010) introduce a new model which allows the parameters to vary across time and flow levels using a weighting technique. The so-called Weighted Regressions on Time, Discharge, and Season (WRTDS) attempt to account for structural changes in the relationship between flow or time and nutrient concentrations (Hirsch *et al.*, 2010), and has been used in several recent studies (Sprague *et al.* (2011) and Kelly *et al.* (2015)).

An issue not addressed in many existing studies, however, is the role of markets and prices. While the signature of agriculture has been identified in long-term analysis of N trends in watersheds (e.g., Turner and Rabalais, 2003; Stets et al., 2015), agriculture could have a range of impacts. The area of various crops, animal numbers, land in conservation, and farming practices all could influence N emissions into streams. Some of these factors change relatively slowly, and are thus correlated closely with the time trend included in most models. For instance, the relative area of different crops is fixed for the growing season and tends to evolve slowly over time. The time trend variables used in many models can control for annual changes in important processes, but one cannot identify particular causal influences on the time trends, such as the impact of changing land uses. On the other hand, farm factors like farm input and output prices change more rapidly, and if prices affect farm decision-making, they could affect short-term fluxes in N emissions. Higher N input prices, for instance, would be expected to reduce N use by farmers, leading to lower N emissions, as shown in Sohngen et al. (2015).

The role of markets and prices has not been widely considered in hydrological models of nutrient fluxes. Due to the potential for omitted variables bias, it may be important to include market prices in models. Prices capture a large amount of economic information that currently is omitted from hydrological models. Omitting variables is not a problem in a regression analysis if the omitted variables are not correlated with the error term in the regression. If, however, the omitted variables are correlated with the error term in the regression, the omission can bias the inference on the other parameters included in the model. In the case of N emissions, fertilizer input decisions by farmers will be affected by N prices, so a set of potentially important variables that have been omitted from most regression models on nutrient concentrations are nutrient prices and crop prices (Hendricks *et al.*, 2014).

As an example in this case, some authors have noted that N concentration trends in Midwestern watersheds have stabilized (Green *et al.* (2014) and N inputs have slowed over time, particularly relative to crop uses (Stets et al., 2015). A key reason for slowing crop uses of N as an input, however, is likely to be rising prices. Thus, while models may estimate that N increases are slowing, the rationale for that slowing increase may be market signals, which would affect everything from the choice of crop, the amount of N to use, the timing of N application (shifting timing to more closely correspond when the crop needs the nutrient), the source of N (animal or purchased). If market signals are having an important impact, then market signals should be included in hydrological models.

Sohngen *et al.* (2015) introduce nutrient and crop prices into a regression model of nutrient (N and P) concentrations, and show that there is a strong relationship between nutrient concentrations and nutrient and crop prices. This relationship makes sense given the well-defined economic link between nutrient prices and nutrient use by farmers: Higher prices cause farmers to use fewer nutrient inputs, and consequently fewer nutrients are emitted from stream. Their model, however, considered relatively small watersheds in Ohio and analyzed annual data.

This paper considers a larger set of watersheds covering the entire Mississippi River Basin. We use monthly data in this analysis, which allows us to examine the short-term influences of price changes on nutrient outcomes. For estimation, we use a five and seven parameter load regression model and augmenting the models with nutrient price and crop price data. We compare and contrast the models with and without the market data and assess how he predicted concentrations change over time. We also test the spatial and temporal relationship between the market factors and their impacts downstream by considering various lag periods for the market data and by considering several different sampling points in the Mississippi River basin.

Model and Data

For this analysis, we start with the seven-parameter load model described in Cohn *et al.* (1992):

$$(1)\ \ln(C) = \beta_0 + \beta_1 \ln\left(\frac{Q}{\tilde{Q}}\right) + \beta_2[\ln\left(\frac{Q}{\tilde{Q}}\right)]^2 + \beta_3\left(T - \tilde{T}\right) + \beta_4\left(T - \tilde{T}\right)^2 + \beta_5 \sin(2\pi T) + \beta_6 \cos(2\pi T) + \varepsilon$$

Where ln() denotes the natural log function, C is the N concentration, Q is the river discharge, T is decimal time measured in years. Following Cohn et al. (1992), $\tilde{Q}$ and $\tilde{T}$ are defined as:

$$(2)\ \tilde{T} = \bar{T} + \frac{\sum_{i=1}^{N}(T_i - \bar{T})^3}{2\sum_{i=1}^{N}(T_i - \bar{T})^2}$$

where

$$(3)\ \bar{T} = \frac{1}{N}\sum_{i=1}^{N} T_i$$

We also consider a five-parameter version of the loading model which drops the squared terms.

$$(4)\ \ln(C) = \beta_0 + \beta_1 \ln(Q) + \beta_2 T + \beta_3 \sin(2\pi T) + \beta_4 \cos(2\pi T) + \varepsilon$$

The squared term for Q and T in equation (1) accounts for potential changes in the relationship between flow or time and concentrations across the spectrum of our observations. It is possible to test for structural shifts in the relationship between T and C in different ways. For instance, one could include dummy (1,0) variables for each year in the regression (omitting a base year) and test for structural shifts in the entire model over time. Alternatively, one could test the interaction between T and Q by including a variable that multiplies the two together. We include models that do both of these in our appendix.

The data considered in this paper were collected between 1977 and 2015 at eight sites in the Mississippi River watershed (Table 1). Six of eight sites in this research are in Iowa and Illinois, and as Goolsby *et al.* (2000) showed, approximately 35% of the total N discharge in the Mississippi River basin are contributed by these two states. Nitrogen concentration and river discharge data are collected from U.S. Geological Survey, nitrogen prices are obtained from a commercial provider of nitrogen prices, Green Markets, and historical corn and soybean prices are collected from Farmdoc database at the University of Illinois.

The specific measure for nitrogen that we use in the paper is the sum of nitrate and nitrite ($NO_2^- + NO_3^-$). All the prices, including nitrogen fertilizer prices, corn prices, and soybean prices have been adjusted to real terms using the Producer Price Index (PPI).

Table 1. Study Sites

SITE ABBREVIATION	SITE NAME
MSSP_CL	Mississippi River at Clinton, IA
IOWA_WAP	Iowa River at Wapello, IA
ILLI_VC	Illinois River at Valley City, IL
MSSP_GR	Mississippi River at Thebes, IL
MIZZ_HE	Missouri River at Hermann, MO
MSSP_TH	Mississippi River at Thebes, IL
OHIO_GRCH	Ohio River at Dam 53 near Grand Chain, IL
MSSP_OUT	Mississippi River above Old River Outflow Channel, LA

In this paper, we introduce nitrogen fertilizer price and corn to soybean price ratio as market factors. The revised model for equation (1) is

(5) $\ln(C) = \beta_0 + \beta_1 \ln\left(\frac{Q}{\tilde{Q}}\right) + \beta_2[\ln\left(\frac{Q}{\tilde{Q}}\right)]^2 + \beta_3\left(T - \tilde{T}\right) + \beta_4 \sin(2\pi T) + \beta_5 \cos(2\pi T) +$

$\beta_6 ln(NP) + \beta_7 ln(CSR) + \varepsilon$

In equations (5), NP is the price of nitrogen and CSR is the ratio of corn to soybean prices.

N prices potentially have had an important effect on nutrient concentrations. From 1977 to the early 1990s, N prices fell in real terms (Figure 1a). This likely encouraged farmers to increase the use of N on farm fields, and potentially encouraged an increase in N emissions from watersheds. Prices rose in the mid-1990s but then started to rise precipitously in the early 2000s as energy prices rose and global economic growth increased rapidly.

Significant concern has been raised in recent years that the increase in corn prices driven partly by ethanol mandates drove more land into corn (Green et al., 2014; Lave et al., 2011; USDA-NASS, 2016). Our measure of the ratio corn to soybean prices to capture the farmer's decision to shift land between corn and soybeans (Figure 1b). We focus on corn and soybeans because the decision to rotate between the two could have large implications for N emissions, given that corn fields have significantly more nitrogen leakage than soybean fields (Randall *et al.*, 2003). Figure 1c shows the change of planting area of corn and soybean in the Mississippi River mainstream basin by states.

Figure 1a. Nitrogen fertilizer price (real prices) through time

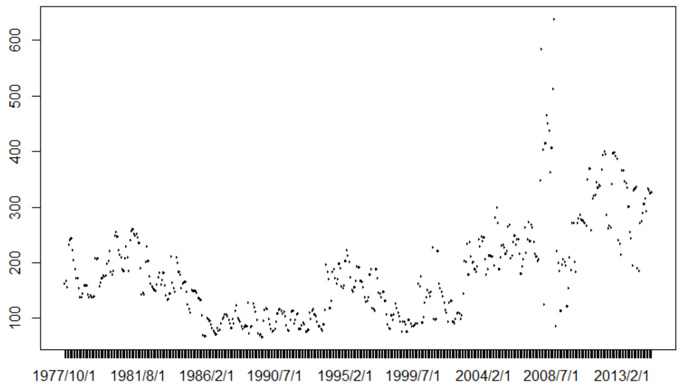


Figure 1b. Corn price to soybean price ratio

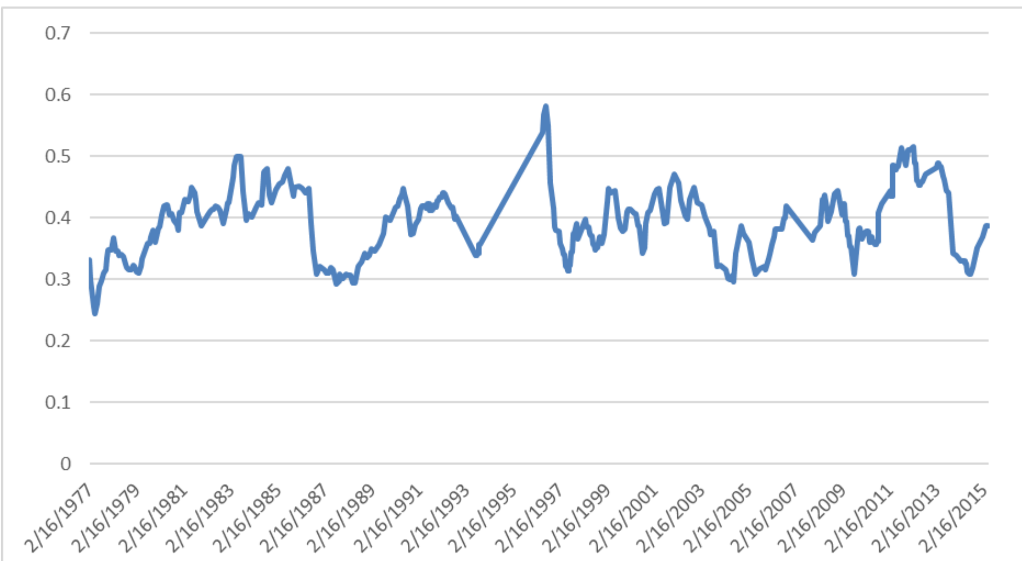
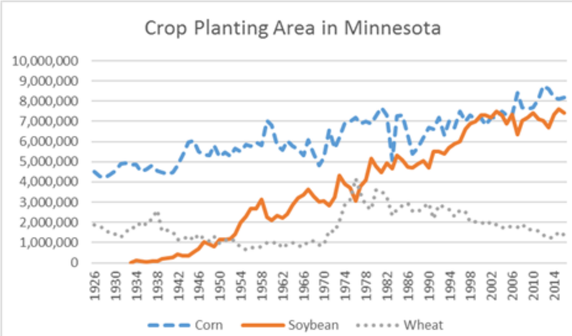
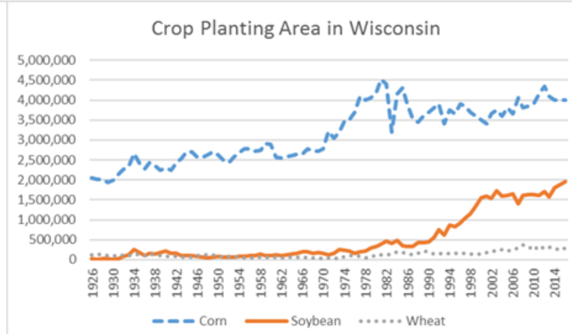
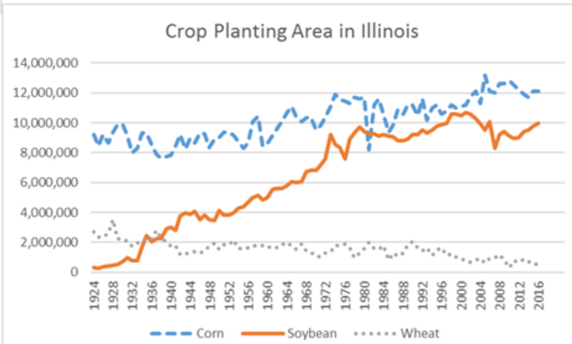
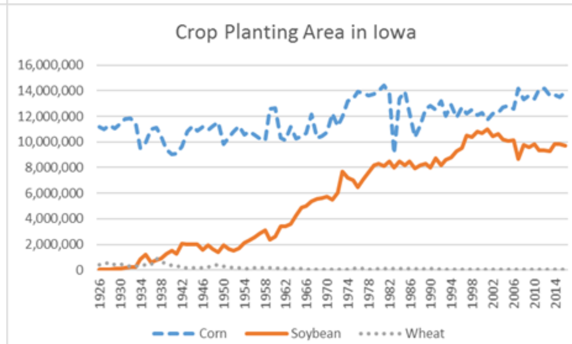


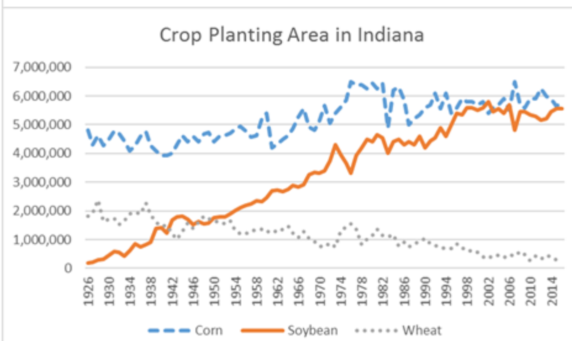
Figure 1c. Area of major crops in the Mississippi River basin

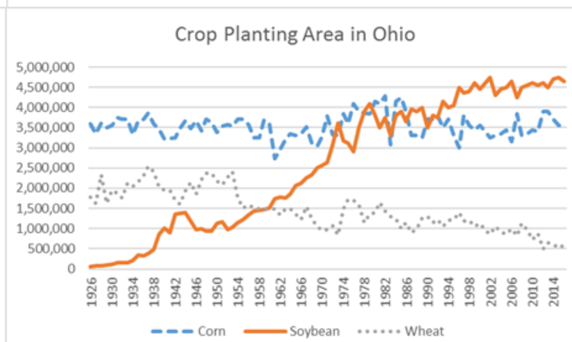

Crop Planting Area in Minnesota
Corn
Soybean
Wheat

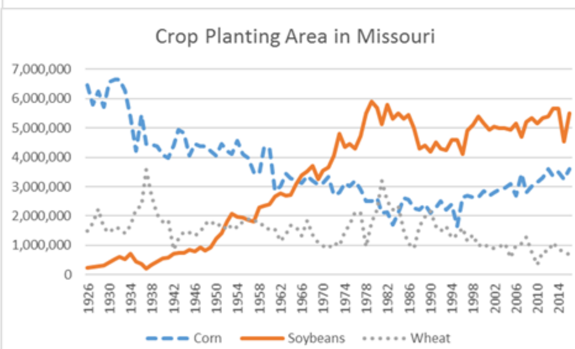

Crop Planting Area in Wisconsin
Corn
Soybean
Wheat

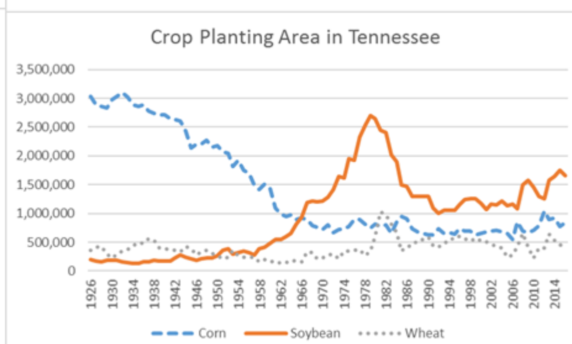

Crop Planting Area in Illinois
Corn
Soybean
Wheat

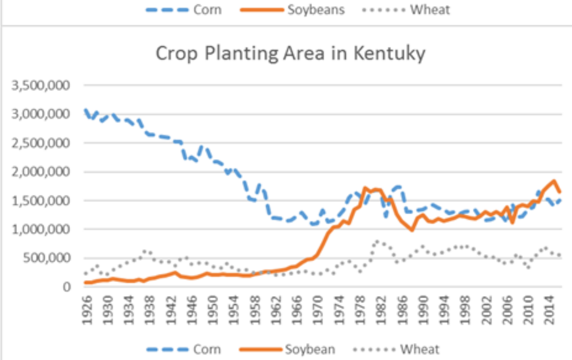

Crop Planting Area in Iowa
Corn
Soybean
Wheat

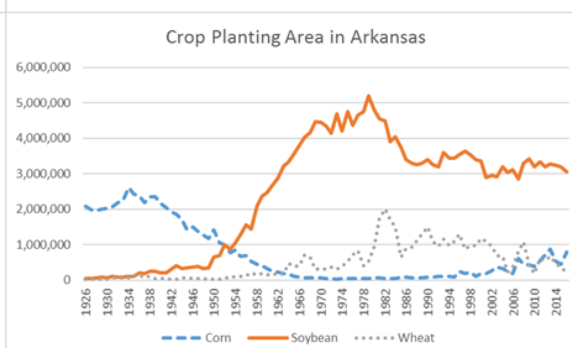

Crop Planting Area in Indiana
Corn
Soybean
Wheat


Crop Planting Area in Ohio
Corn
Soybean
Wheat


Crop Planting Area in Missouri
Corn
Soybeans
Wheat


Crop Planting Area in Tennessee
Corn
Soybean
Wheat


Crop Planting Area in Kentuky
Corn
Soybean
Wheat


Crop Planting Area in Arkansas
Corn
Soybean
Wheat

In the analysis, we lag both price variables to account for the time it takes for management decisions on the farm level to have an impact on N levels downstream. We also test for the most appropriate lag period. For one month lag we use nitrogen price in the previous month, for two or more months lag we use the average nitrogen prices. For example, if the concentration is measured in May 1, a two months lag uses the average price of March and April, a three months lag uses the average price from Feburary to April, etc. For this analysis, we test time lags from one month to twelve months, to determine whether the lag time has implications for nitrogen concentrations.

Results and Discussion

Based on equation (5), we find that the parameter on nitrogen price is negative and significant in five of the eight watersheds, except the Ohio River and the Mississippi outflow. A negative N price coefficient is expected given that a higher N price would encourage farmers to reduce their consumption of N as an input. Higher N prices may also shift some cropland from N-intensive crops into less N-intensive crops, like soybeans. The parameter for the Ohio River is positive, but insignificant while the parameter for the Mississippi outflow is negative and insignificantly different from 0. One confound in the Ohio River basin is that the watershed has a higher proportion of non-agricultural land uses, i.e., it is heavily forested, and a significant portion of the flow is controlled by dams. Now there are 20 dams on the Ohio River. Another confound is the role of N deposition, which is greater in the east than the Upper Mississippi River basin (Boyer *et al.*, 2002). N deposition in Eastern US has been increasing during the past thirty years, and it is still increasing (Galloway *et al.*, 2004). When N deposition becomes a significant source of nitrogen in Eastern US, the nitrogen concentration in the Ohio River would also be influenced by N deposition, which is not a variable in models in this paper. Thus, nitrogen fertilizer and crop prices may not be adequate to measure nitrogen concentration in the Ohio River. As the second largest river in the United States, emissions from the Ohio River would largely influence the nitrogen concentration at the estuary of the Mississippi River, which could be one reason for the insignificant nitrogen price parameter at MSSP_OUT.

The parameter on the corn-soybean price ratio is positive and significant in four of the watersheds, negative and significant in one of them, and insignificantly different from 0 in the other watersheds. Unlike the results for N prices, which are insignificant for the Mississippi outflow, higher corn to soybean prices suggests higher emissions of N. This suggests that at the basin level, shifts in market conditions can have an impact on overall N emissions. This effect, however, does not hold for all of the watersheds upstream. For instance, the results for IOWA_WAP, which encompasses the northeastern part of Iowa, higher corn prices relative to soybean prices appear to lead to lower nitrogen emissions. This result is consistent with Sohngen et al. (2015) who also found a positive relationship between corn prices and N concentrations in a selection of Ohio watersheds. This does contrast with Hendricks *et al.* (2014), who suggest that higher prices for corn relative to soybean should lead to large emissions, but their result likely is largely be a function of the assumptions of the underlying hydrological models that they use. Green et al. (2014) show that higher levels of N applications occurred in the 2000s, while N concentrations trended downward, suggesting that that other processes such as temperature, precipitation, groundwater, and other factors, may have more important influences upon N concentrations than N inputs (Green et al., 2014).

Given the log-log form with respect to prices, the parameter estimates on N and CSR can be interpreted as elasticities. The price elasticity of N export in these watersheds with respect to

N prices ranges from -0.11 to -0.2, suggesting that each 10% increase in N prices will reduce N outputs in the watershed by 1.1% to 2%. Importantly, however, the main Mississippi outflow watershed is not significant, suggesting that price controls could have important local consequences, but they may not alter total N emissions from the watersheds.

Table 2. Model Parameter Estimates Based on the Complete Data Sets (without T-square)

	ILLI_VC			IOWA_WAP			MIZZ_HE			OHIO_GRCH		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	2.315	0.220	***	2.127	0.531	***	1.100	0.366	**	-0.097	0.237	
ln(Q/Q0)	0.055	0.043		-0.184	0.084	*	0.122	0.083		-0.101	0.045	*
ln(Q/Q0)^2	-0.140	0.027	***	-0.309	0.024	***	-0.164	0.060	**	-0.237	0.028	***
T-T0	-0.001	0.002		0.004	0.004		0.011	0.003	***	0.000	0.002	
(T-T0)^2	-	-		-	-		-	-		-	-	
ln(NP)	-0.120	0.037	**	-0.115	0.083		-0.192	0.063	**	0.015	0.041	
ln(CSR)	0.254	0.123	*	-0.662	0.216	**	-0.122	0.190		-0.124	0.124	
Amplitude	0.343	0.027		0.548	0.049		0.453	0.039		0.260	0.033	
Peak day	Mar. 4	4.5		Feb.2	5.2		Mar.28	5.0		Mar.30	7.4	
Adjusted R-suqared	0.502			0.614			0.309			0.446		

	MSSP_CL			MSSP_GR			MSSP_TH			MSSP_OUT		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	2.398	0.252	***	2.135	0.591	***	2.000	0.256	***	0.654	0.202	**
ln(Q/Q0)	0.112	0.048	*	0.174	0.100	.	0.118	0.058	*	-0.024	0.045	
ln(Q/Q0)^2	-0.102	0.031	**	-0.148	0.048	**	-0.295	0.050	***	-0.210	0.037	***
T-T0	0.000	0.002		0.011	0.007		0.001	0.002		-0.002	0.001	
(T-T0)^2	-	-		-	-		-	-		-	-	
ln(NP)	-0.132	0.042	**	-0.206	0.104	*	-0.167	0.044	***	-0.014	0.034	
ln(CSR)	0.294	0.135	*	-0.119	0.247		0.285	0.134	*	0.293	0.102	**
Amplitude	0.337	0.030		0.315	0.048		0.253	0.029		0.234	0.023	
Peak day	Mar.2	5.1		Mar.6	8.8		Oct.5	6.6		Nov.19	5.7	
Adjusted R-suqared	0.447			0.400			0.415			0.316		

*** Statistically different form zero at 0.1% level
** Statistically different form zero at 1% level
* Statistically different form zero at 5% level
. Statistically different from zero at 10% level

Table 3 presents the simulation results using actual crop prices instead of the price ratio. In this table we can distinguish the influence made by specific crops. In Iowa River basin, the change of corn price significantly affects the nitrogen concentration. Nitrogen concentration in Lower Mississippi River seems to be influenced more by soybean price. In Illinois River Basin and Upper Mississippi River, corn and soybean prices make equal influences.

Table 3. Model Parameter Estimates Based on the Complete Data Sets (using actual crop prices)

	ILLI_VC			IOWA_WAP			MIZZ_HE			OHIO_GRCH		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	2.259	0.233	***	1.724	0.546	**	1.124	0.388	**	-0.121	0.252	
ln(Q/Q0)	0.056	0.043		-0.148	0.084	.	0.122	0.083		-0.100	0.045	*
ln(Q/Q0)^2	-0.141	0.027	***	-0.300	0.024	***	-0.164	0.060	**	-0.236	0.028	***
T-T0	-0.001	0.002		-0.001	0.004		0.011	0.004	**	-0.001	0.002	
(T-T0)^2												
ln(NP)	-0.107	0.056	.	0.065	0.112		-0.202	0.093	*	0.038	0.058	
ln(CP)	0.216	0.126	.	-0.757	0.216	***	-0.117	0.191		-0.112	0.126	
ln(SP)	-0.240	0.140	.	0.433	0.241	.	0.134	0.213		0.069	0.136	
Adjusted R-suqared	0.508			0.623			0.318			0.454		

	MSSP_CL			MSSP_GR			MSSP_TH			MSSP_OUT		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	2.417	0.267	***	2.149	0.585	***	1.881	0.274	***	0.455	0.215	*
ln(Q/Q0)	0.112	0.048	*	0.212	0.101	*	0.129	0.058	*	-0.009	0.045	
ln(Q/Q0)^2	-0.101	0.031	**	-0.133	0.049	**	-0.285	0.050	***	-0.199	0.038	***
T-T0	0.000	0.003		0.010	0.007		-0.002	0.003		-0.004	0.002	*
(T-T0)^2												
ln(NP)	-0.129	0.063	*	-0.119	0.112		-0.099	0.065		0.053	0.049	
ln(CP)	0.328	0.137	*	-0.140	0.240		0.275	0.135	*	0.198	0.103	.
ln(SP)	-0.330	0.149	*	-0.131	0.268		-0.401	0.148	**	-0.323	0.112	**
Adjusted R-suqared	0.455			0.421			0.426			0.326		

*** Statistically different form zero at 0.1% level
** Statistically different form zero at 1% level
* Statistically different form zero at 5% level
. Statistically different from zero at 10% level

The results of our tests on the appropriate time lag for the price series are shown in Table 4. In general, the results do not change significantly over a year long period. For watersheds with a coefficient that is negative and significant in the first month's lag, the coefficients are still negative and significant at 12 months. This may seem surprising but suggests that higher prices in previous periods reduce N emissions over up to a year-long period.

Table 4. Time lag test for complete datasets

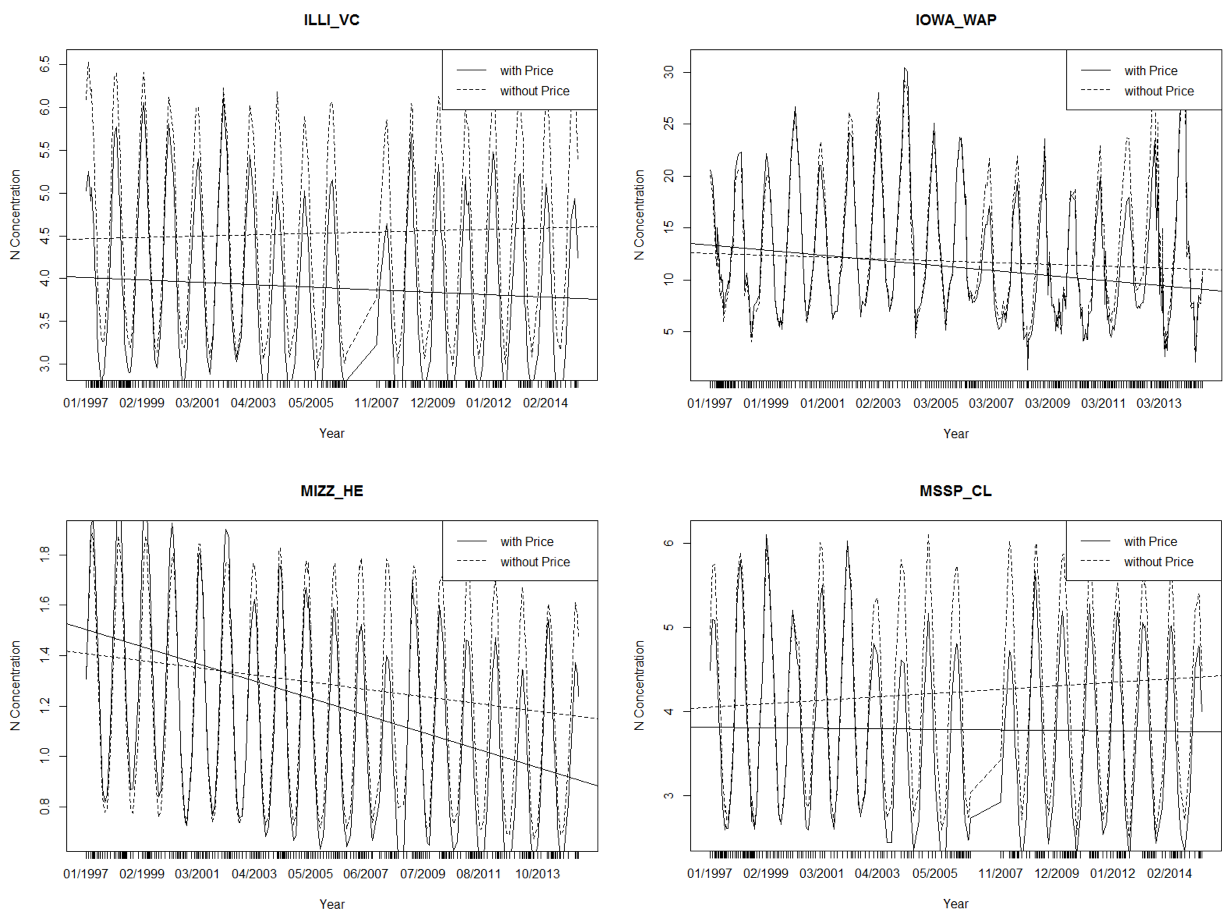
Month lagged	ILLI_VC		IOWA_WAP		MIZZ_HE		OHIO_GRCH	
	Parameter	Pr(>|t|)	Parameter	Pr(>|t|)	Parameter	Pr(>|t|)	Parameter	Pr(>|t|)
1	-0.103989	0.00451 **	-0.101601	0.222069	-0.170905	0.00671 **	0.017116	0.6741
2	-0.096046	0.00847 **	-0.083066	0.325547	-0.170266	0.00751 **	0.015146	0.7126
3	-0.099187	0.00701 **	-0.08109	0.344265	-0.163351	0.011211 *	0.014103	0.7342
4	-0.103489	0.00526 **	-0.086663	0.318972	-0.157425	0.01558 *	0.019354	0.6449
5	-0.10603	0.00458 **	-0.097803	0.265988	-0.155768	0.0179 *	0.025699	0.5455
6	-0.110067	0.00353 **	-0.112862	0.203736	-0.151629	0.02255 *	0.040621	0.342
7	-0.113062	0.00298 **	-0.12571	0.1606	-0.146243	0.0293 *	0.04491	0.2987
8	-0.109948	0.00414 **	-0.129773	0.1509	-0.145267	0.03209 *	0.047668	0.2745
9	-0.114725	0.00299 **	-0.130588	0.151615	-0.14919	0.02899 *	0.052434	0.2335
10	-0.121566	0.00175 **	-0.116613	0.20029	-0.150846	0.02849 *	0.051283	0.2476
11	-0.126596	0.0012 **	-0.10104	0.266736	-0.15267	0.02792 *	0.050179	0.2617
12	-0.132898	0.000719 ***	-0.104987	0.25176	-0.163934	0.01895 *	0.047867	0.2874

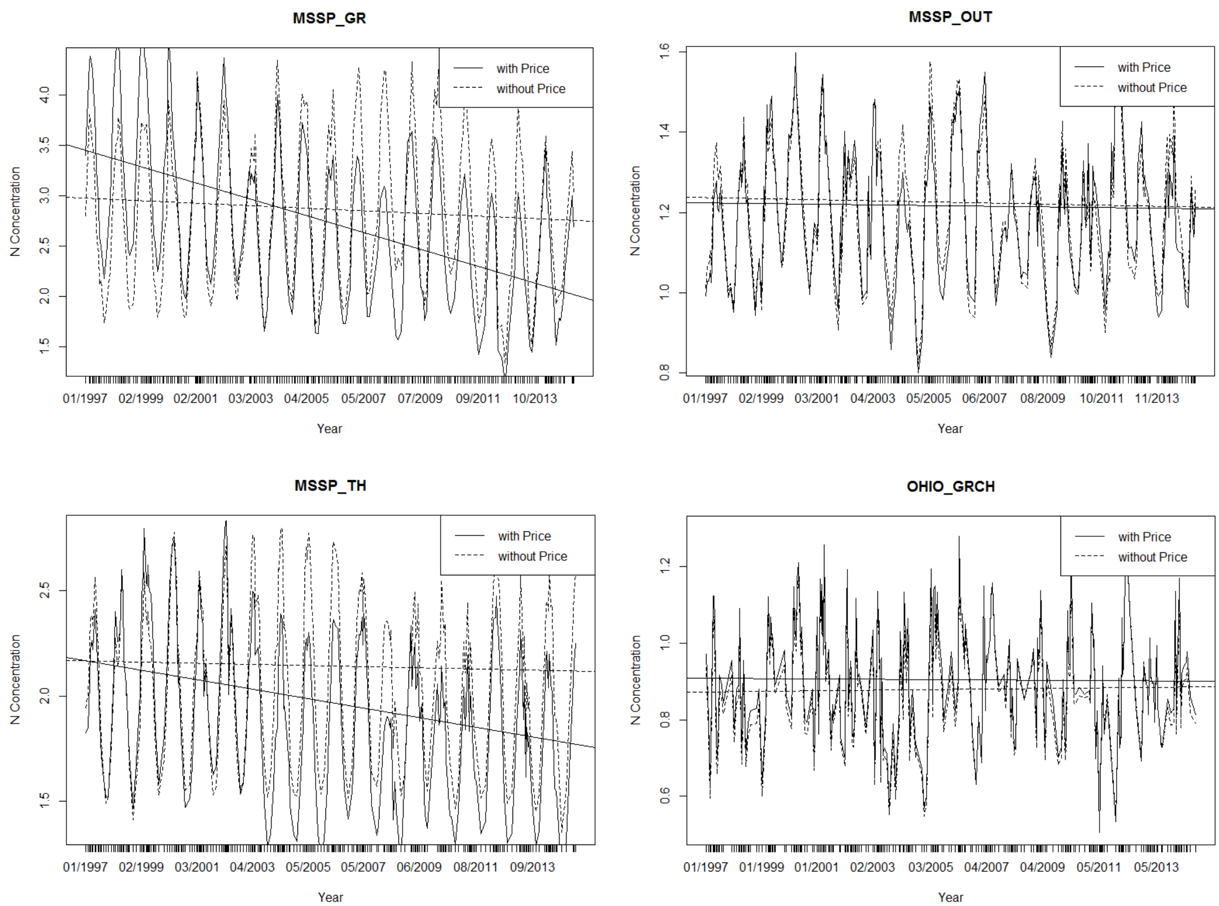
Month Lagged	MSSP_CL		MSSP_GR		MSSP_TH		MSSP_OUT	
	Parameter	Pr(>|t|)	Parameter	Pr(>|t|)	Parameter	Pr(>|t|)	Parameter	Pr(>|t|)
1	-0.111626	0.007775 **	-0.129178	0.21597	-0.149517	0.000689 ***	-0.004394	0.89757
2	-0.107097	0.010558 *	-0.086097	0.42467	-0.148531	0.000839 ***	-0.001219	0.97173
3	-0.111976	0.008091 **	-4.79E-02	0.66689	-0.145315	0.00118 **	0.004832	0.88902
4	-0.121188	0.004478 **	-0.038548	0.73702	-0.1394	0.00198 **	0.009473	0.7859
5	-0.128854	0.002737 **	-0.024856	0.83286	-0.11947	0.00712 **	0.014648	0.6763
6	-0.135941	0.001738 **	-0.021071	0.86137	-0.118104	0.00844 **	0.015951	0.6521
7	-0.140409	0.001366 **	-0.030668	0.80373	-0.113939	0.0118 *	0.024859	0.4849
8	-0.136818	0.001985 **	-0.036753	0.77024	-0.110911	0.0152 *	0.033455	0.3502
9	-0.142215	0.001443 **	-0.020262	0.869	-0.115148	0.0125 *	0.037931	0.2937
10	-0.150226	0.000827 ***	0.009972	0.931213	-0.114651	0.0135 *	0.040067	0.27143
11	-0.155976	0.000569 ***	0.017078	0.884978	-0.119513	0.0106 *	0.037486	0.307
12	-0.163886	3.22E-04 ***	0.014872	0.901981	-0.129079	0.00605 **	0.036409	0.325

*** Statistically different form zero at 0.1% level
** Statistically different form zero at 1% level
* Statistically different form zero at 5% level
. Statistically different from zero at 10% level

The results suggest that market factors may have an important influence on N emissions in the Mississippi River basin. One way to account for their impact is to compare models with and without the relevant price indicators. The corresponding model for Figure 2 without the price variables is shown in the appendix. To assess the influence of prices on the outcomes, we start by developing predictions of N concentrations in the models with and without the price variables (Figure X). We then calculate a trend variable which shows the overall trend in N concentrations in these watersheds over the time period of observation. This trend is the predicted trend in concentrations, taking all factors into account. In each case, the trend from the model with market prices is lower. That is, the models with the price variables all indicate that the trend in N emissions has been downward in these watersheds over the time period of analysis. The two cases where we do not find a large difference in the trends for the predicted outcomes with prices and without are the Ohio River and the outflow of the Mississippi River. This makes sense given that the price variables are not significant in the models.

Figure 2. the regression results of the NASQAN model and model with market factors





Conclusion and Discussion

This study discussed the relationship between market factors and nitrogen concentration in the Mississippi River. Our estimate of nitrogen concentration elasticity in response to nitrate fertilizer price is between -0.11 and -0.2 in several observation sites including Herman, MO, Clinton, IA, Grafton, IL, Thebes, IL, and Valley City, IL. Also, the nitrogen concentration elasticity in response to corn/soybean price ratio is between -0.25 and -0.3 in Valley City, IL, Clinton, IA, Thebes, IL, and Mississippi River Outflow Channel, LA.

Our results illustrate the importance of market factors when estimating nitrogen concentration in watersheds. Market factors are important because if the government needs the estimation of nitrogen concentration as an assist of making policies, a mistake of overestimation has a large probability to happen if market factors were not considered. As we estimated, time lag effect is not significant on estimating nitrogen concentration according to our study. Also, our results bolster the view that price mechanisms can be used to help control nitrogen concentration in watersheds. This study implies that a 10% increase on nitrogen price can lead a 1.1-2.0% decrease in nitrogen concentration. Crop prices may also be an impacting factor, but its role needs further study.

This study still has some restrictions and can be improved. A study of eight sites can illustrate the importance of market factors, but it is not enough to reveal the regularity of regional patterns. In other words, now that we have found market factors are important, the following question is why in different regions market factors, especially nitrogen fertilizer prices, shows different significance. If such regularity can be found, the relationship between market factors and nitrogen concentration can be more detailed by region. Such relationship can provide stronger support to policy maker when using price mechanism.

Appendix

This appendix presents estimates of original NASQAE model and WRTDS model. Using data from the same eight sites along the Mississippi River, these tables are provided to show the nitrogen flux simulation before adding market factors.

(See Tables A1 – A3)

Table A1. Model Parameter Estimates Based on WRTDS Model

	ILLI_VC			IOWA_WAP			MIZZ_HE			OHIO_GRCH		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	1.444	0.026	***	2.609	0.080	***	0.228	0.047	***	0.034	0.029	
ln(Q/Q0)	0.243	0.025	***	0.779	0.042	***	0.314	0.048	***	0.187	0.031	***
ln(Q/Q0)^2	-	-		-	-		-	-		-	-	
T-T0	-0.003	0.002	.	-0.006	0.003	.	0.007	0.003	**	0.000	0.002	
(T-T0)^2	-	-		-	-		-	-		-	-	
ln(NP)	-	-		-	-		-	-		-	-	
ln(CSR)	-	-		-	-		-	-		-	-	
Amplitude	0.335	0.027		0.576	0.049		0.448	0.039		0.257	0.033	
Peak day	Mar.4	4.6		Jan.30	5.0		Mar.28	5.1		Mar.31	7.5	
Adjusted R-suqared	0.464			0.486			0.292			0.3699		

	MSSP_CL			MSSP_GR			MSSP_TH			MSSP_OUT		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	1.431	0.028	***	1.239	0.054	***	0.854	0.030	***	0.284	0.019	***
ln(Q/Q0)	0.246	0.028	***	0.438	0.052	**	0.392	0.040	***	0.156	0.035	***
ln(Q/Q0)^2	-	-		-	-		-	-		-	-	
T-T0	-0.002	0.002		-0.003	0.004		-0.002	0.002		-0.002	0.001	
(T-T0)^2	-	-		-	-		-	-		-	-	
ln(NP)	-	-		-	-		-	-		-	-	
ln(CSR)	-	-		-	-		-	-		-	-	
Amplitude	0.328	0.030		0.308	0.047		0.253	0.029		0.232	0.023	
Peak day	Mar.2	5.2		Mar.11	8.9		Oct.5	6.7		Nov.10	5.8	
Adjusted R-suqared	0.420			0.377			0.354			0.272		

*** Statistically different form zero at 0.1% level

** Statistically different form zero at 1% level

* Statistically different form zero at 5% level

Table A2. Model Parameter Estimates Based on NASQAE Model

	ILLI_VC			IOWA_WAP			MIZZ_HE			OHIO_GRCH		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	1.569	0.031	***	2.208	0.089	***	0.294	0.054	***	0.086	0.034	*
ln(Q/Q0)	0.060	0.042		-0.187	0.084	*	0.122	0.084		-0.099	0.045	*
ln(Q/Q0)^2	-0.140	0.265	***	-0.313	0.024	***	-0.163	0.060	**	-0.236	0.028	***
T-T0	-0.003	0.001	.	-0.002	0.003		0.007	0.003	**	0.000	0.002	
(T-T0)^2	-0.001	0.000	***	0.000	0.000		0.000	0.000	.	0.000	0.000	
ln(NP)	-	-		-	-		-	-		-	-	
ln(CSR)	-	-		-	-		-	-		-	-	
Amplitude	0.350	0.026		0.531	0.049		0.447	0.039		0.257	0.033	
Peak day	Mar.4	4.2		Feb.2	5.4		Mar.28	5.1		Mar.30	7.5	
Adjusted R-suqared	0.514			0.605			0.302			0.446		

	MSSP_CL			MSSP_GR			MSSP_TH			MSSP_OUT		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	1.560	0.034	***	1.326	0.065	***	0.969	0.035	***	0.320	0.024	***
ln(Q/Q0)	0.121	0.047	*	0.212	0.099	*	0.123	0.058	*	-0.024	0.045	
ln(Q/Q0)^2	-0.100	0.030	**	-0.133	0.048	**	-0.300	0.050	***	-0.213	0.038	***
T-T0	-0.002	0.002		-0.001	0.004		-0.001	0.002		-0.002	0.001	
(T-T0)^2	-0.001	0.000		-0.002	0.001	***	-0.001	0.000	***	0.000	0.000	
ln(NP)	-	-		-	-		-	-		-	-	
ln(CSR)	-	-		-	-		-	-		-	-	
Amplitude	0.346	0.029		0.313	0.047		0.254	0.029		0.233	0.024	
Peak day	Mar.3	4.8		Mar.8	8.6		Oct.5	6.6		Nov.19	5.9	
Adjusted R-suqared	0.460			0.418			0.410			0.308		

*** Statistically different form zero at 0.1% level
** Statistically different form zero at 1% level
* Statistically different form zero at 5% level
. Statistically different from zero at 10% level

Table A3. Model Parameter Estimates Based on NASQAE Model (without T-square)

	ILLI_VC			IOWA_WAP			MIZZ_HE			OHIO_GRCH		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	1.474	0.026	***	2.149	0.079	***	0.247	0.048	***	0.096	0.028	***
ln(Q/Q0)	0.049	0.043		-0.198	0.084	*	0.138	0.083	.	-0.099	0.045	*
ln(Q/Q0)^2	-0.146	0.027	***	-0.316	0.024	***	-0.154	0.060	*	-0.236	0.028	***
T-T0	-0.003	0.001	.	0.000	0.003		0.007	0.003	**	0.000	0.002	
(T-T0)^2	-	-		-	-		-	-		-	-	
ln(NP)	-	-		-	-		-	-		-	-	
ln(CSR)	-	-		-	-		-	-		-	-	
Adjusted R-suqared	0.490			0.604			0.299			0.447		

	MSSP_CL			MSSP_GR			MSSP_TH			MSSP_OUT		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	1.455	0.028	***	1.195	0.055	***	0.900	0.030	***	0.316	0.019	***
ln(Q/Q0)	0.111	0.048	*	0.159	0.100		0.115	0.059	.	-0.013	0.045	
ln(Q/Q0)^2	-0.105	0.031	***	-0.158	0.048	**	-0.312	0.050	***	-0.213	0.038	***
T-T0	-0.002	0.002		-0.001	0.004		-0.001	0.002		-0.002	0.001	
(T-T0)^2	-	-		-	-		-	-		-	-	
ln(NP)	-	-		-	-		-	-		-	-	
ln(CSR)	-	-		-	-		-	-		-	-	
Adjusted R-suqared	0.432			0.396			0.397			0.310		

*** Statistically different form zero at 0.1% level
** Statistically different form zero at 1% level
* Statistically different form zero at 5% level
. Statistically different from zero at 10% level

We also simulated nitrogen concentration with different parameters when market factors exist.

$$(6)\ \ln(C) = \beta_0 + \beta_1 \ln\left(\frac{Q}{\tilde{Q}}\right) + \beta_2\left(T - \tilde{T}\right) + \beta_3 \sin(2\pi T) + \beta_4 \cos(2\pi T) + \beta_5 ln(NP) + \beta_6 ln(CSR) + \varepsilon$$

$$(7)\ \ln(C) = \beta_0 + \beta_1 \ln\left(\frac{Q}{\tilde{Q}}\right) + \beta_2[\ln\left(\frac{Q}{\tilde{Q}}\right)]^2 + \beta_3\left(T - \tilde{T}\right) + \beta_4\left(T - \tilde{T}\right)^2 + \beta_5 \sin(2\pi T) + \beta_6 \cos(2\pi T) + \beta_7 ln(NP) + \beta_8 ln(CSR) + \varepsilon$$

The first model we examine is equation (6), ignoring the squared terms for flow and time (Table A4). The parameter on flow is positive and significant in all cases while the parameter on time is positive in all cases but only significant in one watershed. The parameter on nitrogen prices is negative for most watersheds, and significant, although the parameter for the Ohio River is positive but insignificant. The parameter estimate can be interpreted as elasticity, which is the %

change in quantity over the percentage change in price. Thus, the price elasticity of nitrogen export in this watersheds ranges from -0.14 to -0.23, which implies that each 10% increase in prices will reduce nitrogen outputs in the watershed by 1.4% to 2.3%. The coefficient on corn to soybean prices is both positive and negative, although it is not significant in most cases.

Table A4. Model Parameter Estimates Based on the Complete Data Sets (without square terms). Parameters on the *sin* and *cos* variables are available upon request.

	ILLI_VC			IOWA_WAP			MIZZ_HE			OHIO_GRCH		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	2.353	0.225	***	3.024	0.598	***	1.040	0.367	**	-0.138	0.253	
ln(Q/Q0)	0.241	0.024	***	0.770	0.042	***	0.309	0.047	***	0.186	0.032	***
ln(Q/Q0)^2	-	-		-	-		-	-		-	-	
T-T0	0.000	0.002		0.001	0.004		0.011	0.003	***	0.000	0.002	
(T-T0)^2	-	-		-	-		-	-		-	-	
ln(NP)	-0.139	0.037	***	-0.213	0.094	*	-0.183	0.063	**	0.011	0.044	
ln(CSR)	0.222	0.126	.	-0.727	0.245	**	-0.116	0.192		-0.126	0.132	
Adjusted R-suqared	0.478			0.501			0.301			0.369		

	MSSP_CL			MSSP_GR			MSSP_TH			MSSP_OUT		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	2.404	0.254	***	2.267	0.597	***	2.071	0.264	***	0.669	0.207	**
ln(Q/Q0)	0.242	0.027	***	0.433	0.053	***	0.379	0.039	***	0.142	0.035	***
ln(Q/Q0)^2	-	-		-	-		-	-		-	-	
T-T0	0.000	0.002		0.010	0.007		0.001	0.002		-0.002	0.001	
(T-T0)^2	-	-		-	-		-	-		-	-	
ln(NP)	-0.141	0.042	***	-0.234	0.105	*	-0.181	0.045	***	-0.021	0.035	
ln(CSR)	0.274	0.136	*	-0.177	0.249		0.328	0.138	*	0.308	0.105	**
Adjusted R-suqared	0.436			0.384			0.377			0.280		

*** Statistically different form zero at 0.1% level
** Statistically different form zero at 1% level
* Statistically different form zero at 5% level
. Statistically different from zero at 10% level

In Table A5, we add the square term on time and flow (Model 6). In this model, the square term on water flow is highly significant and tends to be negative, suggesting a nonlinear relationship, with a positive relationship between flow and concentration at low flows and a negative relationship at high flows. The parameter on time squared is either 0 and insignificantly different from 0, or negative and significantly different from 0 in the case of ILL_VC and MISS_GR. Combined these results suggest that there has been very little change in the trend in nitrates in any of these watersheds over time, in general, however, the negative and significant sign on the squared term suggests that the trend may be turning downward. That is, the relationship between time and concentration appears to be concave, so that over time, the parameter on the time variable will tend to slope downward, implying that concentrations may indeed be sloping downward. The estimated parameter for nitrogen price is either not significant or negative and significant, as expected. We also tested whether adding or removing variables would change the amplitude and peak day of nitrogen concentration (Table 2, Table A1, A2, A5). According to those tables, adding price variables has little change on nitrogen concentration amplitude and peak day.

Table A5. Model Parameter Estimates Based on the Complete Data Sets (with square terms)

	ILLI_VC			IOWA_WAP			MIZZ_HE			OHIO_GRCH		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	1.491	0.308	***	2.035	0.620	**	1.309	0.508	*	-0.081	0.317	
ln(Q/Q0)	0.053	0.042		-0.184	0.084	*	0.126	0.083		-0.100	0.045	*
ln(Q/Q0)^2	-0.144	0.027	***	-0.309	0.024	***	-0.161	0.060	**	-0.236	0.003	***
T-T0	-0.004	0.002	*	0.003	0.003		0.012	0.003	***	0.000	0.002	
(T-T0)^2	-0.001	0.000	***	0.000	0.000		0.000	0.000		0.000	0.000	
ln(NP)	0.048	0.057		-0.096	0.107		-0.233	0.094	*	0.012	0.058	
ln(CSR)	0.163	0.124		-0.667	0.217	**	-0.097	0.195		-0.122	0.127	
Amplitude	0.346	0.026		0.547	0.049		0.453	0.039		0.260	0.033	
Peak day	Mar. 4	4.3		Feb.2	5.2		Mar.28	5.0		Mar.30	7.4	
Adjusted R-suqared	0.514			0.612			0.308			0.445		

	MSSP_CL			MSSP_GR			MSSP_TH			MSSP_OUT		
	Coefficient	SE		Coefficient	SE		Coefficient	SE		Coefficient	SE	
Constant	1.517	0.252	***	2.156	0.580	***	1.812	0.352	***	0.073	0.264	**
ln(Q/Q0)	0.114	0.048	*	0.224	0.099	*	0.119	0.058	*	-0.233	0.045	
ln(Q/Q0)^2	-0.104	0.031	***	-0.125	0.048	**	-0.294	0.050	***	-0.211	0.038	***
T-T0	-0.003	0.002	.	0.009	0.206		0.001	0.002		-0.002	0.002	
(T-T0)^2	-0.001	0.000		-0.002	0.001	***	0.000	0.000		0.000	0.000	
ln(NP)	0.047	0.042		-0.177	0.102	.	-0.129	0.065	*	-0.029	0.048	
ln(CSR)	0.192	0.135		-0.076	0.243		0.262	0.137	.	0.301	0.103	**
Amplitude	0.341	0.029		0.315	0.047		0.254	0.029		0.234	0.023	
Peak day	Mar.2	4.9		Mar.5	8.7		Oct.5	6.6		Nov.19	5.7	
Adjusted R-suqared	0.461			0.421			0.415			0.316		

*** Statistically different form zero at 0.1% level
** Statistically different form zero at 1% level
* Statistically different form zero at 5% level
. Statistically different from zero at 10% level

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